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NPL REPORT
DEM Ultrafast and Dielectric Materials DEM-EM 006

An assessment of measurement requirements for the optical datacomms industry

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NOT RESTRICTED

NOVEMBER 2004

NDED BY THE DTI

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An assessment of measurement requirements for the optical datacomms industry

David Humphreys and Fabrice Bernard
Division of Enabling Metrology

ABSTRACT

This a report summarising the measurement requirements of the datacommunications industry for optoelectronic components determined by industry consultation. NPL's efforts in the 2004-2007 programme will concentrate on three areas: optical waveform related measurements (waveform, chirp and jitter) to provide interoperability support for different transponder types; multimode fibre bandwidth measurements; metrological support for fibre to the home/premises systems using passive optical networks and contribution to standards bodies.

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ISSN 1744-0483

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Approved on behalf of the Managing Director, NPL
by Stuart Pollitt, Director, Division of Enabling Metrology

1. Executive Summary

This document is the first deliverable for Project 2.2, Measurements for Optical Datacomms Technologies of the National Measurement System (NMS) 2004-2007 Photonics Metrology programme, Theme 2 (Photonic Communications).

The consultation process for the study proceeded in two stages. Information was gathered and broad questions were posed to UK and overseas contacts and then a more detailed work plan was circulated for comment. The latter provoked greater response from industry and forms the basis for the project plans.

Three key groupings in the datacomms area are:

- Fibre to the home/premises. A growth area, but investment lags in the UK compared to USA and Japan.
- Groups of computers linked together by an optical local area network, typically on a single site. The transmission systems often adhere to the ANSI Fibre Channel specifications*. These systems currently operate at a short wavelength (850 nm) over multimode fibre using a data rate of 1-4 Gb/s.
- Core transport datacomms and telecomms. There is convergence of the two systems as IP is being increasingly adopted.

In all these areas, component cost is an issue as there are other competing technologies. Also, the structure of the component market has changed from vertical to horizontal integration and many components are now in developed under *Multi-Source Agreements* (MSA). Interoperability within a single component class such as XFP and compatibility between different specifications are important issues.

NPL's expertise lies with physical measurement and provision of traceable access to standards. Although this restricts the scope to within the physical layer of a transmission system, the way in which the data is formatted for transmission can have direct effect on the transmitted signal. An example of this problem is pattern dependent jitter. The reproducibility of jitter measurements is poor. Measurement results at 10 Gb/s for the same component, made with the same type of instrument at different locations may differ by as much 30%. This leads to issues of tolerancing and quality control during manufacture.

This project is underpinned by work currently in progress within the Theme 6 of the NMS 2003-2006 Electrical Programme. There is also considerable synergy with the network-modelling project within the Photonics Programme (project 2.4). In order to maximise the impact, NPL should aim to work in collaboration with industrial companies, standards bodies or trade associations if possible to ensure focus. The choice of research should reflect the timescales for the adoption by industry of the different datacommunications technologies. The key areas that have been identified are:

- Optical waveform related measurements (early within the project). This provides active support for measurements of jitter and allows impartial investigation of interoperability between component vendors. Depending on

* http://www.t11.org/index.htm

resources, this could be extended to provide validated stressed-eye measurements and an underpinning for dispersion penalty. The degradation of electrical waveforms used to drive transponders may also need to be measured.

- Support for multimode fibre bandwidth measurements (Fibre Channel operating at 850 nm).
- Support for Fibre to the home/premises systems using passive optical networks (towards the end of the project). These systems will need to be low-cost but also have complex metrological issues.
- Contribution to standards bodies (throughout the project). It is anticipated that many measurement related issues would be raised and agreed upon within these committees.

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3. Introduction

3.1. This document

This document is the first deliverable for Project 2.2, Measurements for Optical Datacomms Technologies of the agreed *National Measurement System* (NMS) 2004-2007 Photonics Metrology programme, Theme 2 (Photonic Communications). It describes the scope and methodology of the industry consultation, the prioritisation and rationale for the proposed tasks, their benefits and deliverables.

3.2. Overview of the Photonics Metrology Programme

The Photonics Metrology 2004-2007 programme is an industry-focused programme. The specific aim of the programme is the continual development of a measurement infrastructure to meet the growing requirements of the UK's photonics industry. This programme comprises of four main themes and programme management. Much of the work within this programme is focused on providing support for new and emerging areas such as displays, medicine and biological measurements. The new work relating to Communications is focused on the datacomms requirement, optical network modelling and support for broadband and access systems. During the previous programme, the work was mainly concentrated on the long-haul telecommunications requirement. The outputs and measurement services from this work are maintained.

4. Scope

In this work, we deliberately set the scope of the study to be broad. This has been done because it is anticipated that the convergence occurring between telecommunications and computing will continue over the next few years. Aspects that we have considered include:

- Requirements arising from the changes in business approach taken within the telecommunications community.
- Requirements arising from the move to *Internet Protocol* (IP)-based systems from *Synchronous Digital Hierarchy* (SDH). This can be viewed as interactions between the physical-layer (Layer 1) and its controlling protocols (Layer 2).
- All previous work concentrated on the needs of the telecommunications industry and so very little was known about the requirements of the computer industry.
- Requirements arising from distribution of data to multiple users (fibre to the home/premises).
- Assessing the role of standardisation bodies as a source of information about future trends and a pinch-point where maximum impact can be achieved.

Once this information had been gathered, the priorities and targets for the remainder of the project were chosen to maximise the impact that could be made with the resources available.

5. Consultation process

A two-stage consultation process has informed the preparation of this document.

1. In the first stage of the consultation process, web-based searches were performed to expand the list of potential contacts and to determine the depth and breadth of standard activities. Because of the global nature of these businesses, the final list was drawn from both UK and overseas contacts. In the initial approach, broad questions were posed to avoid forcing a particular path.

2. The replies that were received were used to form a proposed work-plan, giving detailed focus. This was then circulated to the contacts for comment and refinement. The responses from industry were highly focused and these form the basis for the project plans.

6. Industry status

Different industries, such as component manufacture and computing, contribute to the overall data communications picture. Despite this diversification, and the current recession in the optical telecommunications sector, there can be no doubt that high-capacity optical-networks will have a major and growing impact in the future, both economically and socially. Internet traffic continues to grow at around 80% per year. The current surplus capacity of backbone networks will be consumed as the development of broadband access technologies accelerates.

6.1. Component manufacture

There have been major changes to this industry over the past two years. Now the component manufacturers are separate and independent from the network manufacturers. A major change that has occurred is that these companies cooperate to form *multi-source-agreements* (MSA). By doing this, the interconnection interfaces become common, leading to the possibility of interoperability (important for competition and trade). The disadvantage with this strategy from their perspective is that the price has reduced but the volume has not increased significantly as yet.

6.2. Computer industry

The technology evolution in the computer industry is still following Moore's law that predicts the number of transistors on an integrated circuit, and thus the speed and the memory of the computers, doubles approximately every 18 months. Current technology allows a feature size of 90 nm and Intel has announced its intention to produce transistors by a 65 nm process in 2005[1].

Processors currently run at up to 3.8 GHz and their speed is likely to increase beyond 4 GHz in the near future. Double-core processors, that will increase the performance of computer without the need to increase the processor clock rate[2], are expected by 2005.

Because of the increase of the processor speed more bandwidth in the data bus is needed to interconnect chips and board inside a computer. To address this problem Intel is currently undertaking research to replace copper based bus connection by an optical bus[3]. Because of the long timescale associated with this work, this area of research can be considered to be beyond the scope of the current project.

The worldwide industry revenue for 2004 will be around 300 billon dollars. The growth for this year is disparate between the different market sectors: +7.6% for PCs, +6.4% for Servers and +0.3% for hard disk drives and +0% for Redundant Array of Independent Disks (RAID) storage. For 2005 the global growth is expected to be around 3%[4].

Intel is involved in optical datacomms research at its laboratory located on the Cambridge University campus. This laboratory works closely with the Centre for Photonics systems at Cambridge University.

6.3. Datacomms industry

The *Information and Communications Technology* (ICT) sector worldwide is expected to grow from £38 billion in 2002 to £45 billion by 2005[5] with a European market of £600 million for test and evaluation in this area[6]. The Government's Foresight studies suggest policies must be designed to achieve internationally agreed open standards in electronics, computing and telecommunications[7].

Because of the lower costs of computing and the importance of data to businesses, *Storage Area Networks* (SAN) are becoming of increasing importance. Corporate data may be backed up remotely over a network, which may include the telecommunications network. Many computer companies are involved in optical datacomms products via their portfolio of solutions for SAN. Companies such as Fujitsu, Fujitsu Siemens Computer, Dell, and Hewlett Packard offer a variety of SAN products.

The majority of the systems that are currently in use are based on the *Fibre Channel* (FC) specifications (ANSI T11)[8]. Much of the currently installed capacity operates at 850 nanometres over multimode fibre with a data rate of between 1 and 2 Gb/s. The transceiver of choice is the *Small Form Factor Plugable* (SFP) unit, as this allows direct field replacement. The standardisation process is in place to increase the speed to 4 Gb/s (2005) and then 8 or 10 Gb/s.

Some equipment vendors have also adopted the XFP 10 Gb/s units, which operate with single-mode fibre. The SFP/Fibre Channel approach allows a smooth degradation path to lower bit rates whereas the XFP 10 Gb/s approach does not have a rate degradation path. There is some question about whether the final FC standards will be at 8 Gb/s or 10 Gb/s and an important influence for this decision will relate to the existing installed capacity of multimode fibre.

6.4. Fibre to the home/premises

Although businesses represent the most demanding use of datacommunications, the number of individual domestic users is high and so their impact will become more significant as the availability of broadband increases.

There is increasing activity in the area of *fibre to the home and fibre to the premises* (FTTx) particularly in the USA and Japan. In Japan, the number of subscribers was over 600,000 in November 2003 and was increasing at a rate of 80,000 subscribers per month at that time[9]. For 2004 the growth will continue and lead to around 1.4 million connections. These projections have been supported by KMI research that

forecast 860,000 connections globally by 2004. It is expected that in the USA FTTx will achieve 30% penetration in approximately five years.

There are two competing technologies for FTTx: the first uses active transponders for both upstream and downstream, creating an architecture similar to telecommunication systems. The alternative is a *passive optical network* (PON), where the light from single transmitter is distributed to typically 32 homes, each of which is equipped with a low-quality transmitter. The upstream link (from the consumer) is time-division multiplexed and each user transmits their data in turn. At a recent conference[†] the relative merits of active and passive systems were discussed. From this discussion it is clear that active systems do not require significant additional metrology. However, the PON networks raise number of measurement issues: dynamic range, wide mark-space ratio data signals and multi-wavelength measurements.

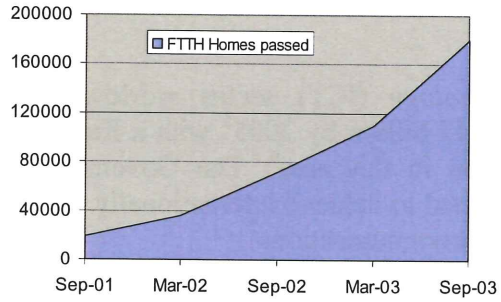


Figure 1 Cumulative installations of fibre to the home North America

Within the UK, passive optical networks are being evaluated as a fibre to the home solution. This work has recently started and is expected to take approximately nine months to one year to complete. If successful, the time for implementation would depend very strongly on economic issues, such as competition with copper-based technologies, such as ASDL, and increased adoption of broadband.

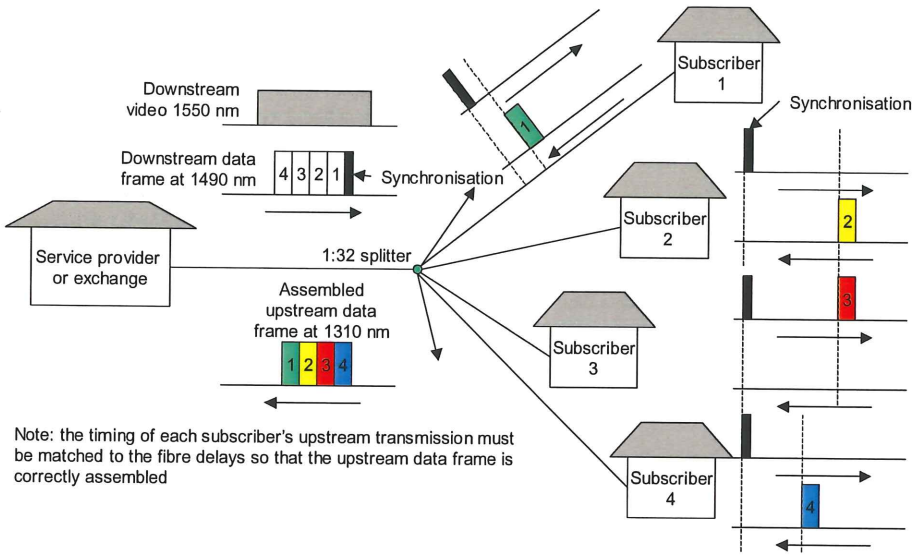


Figure 2 Illustration of time-division multiplexing between subscribers in a PON environment

[†] 'Symposium on Optical Fiber Measurements (SOFM 2004)', NIST, Boulder, CO, USA, 28-30 Sept. 2004.

6.5. Instrumentation industry

The instrumentation industries are still suffering from the collapse of the telecommunications industry. Much of the equipment that had been purchased during the boom period was sold for a fraction of the original price. This caused a glut of high-quality telecommunications instrumentation in the market.

New areas such as FTTx using passive optical networks are expected to have new metrology problems, and hence the need for new instrumentation.

6.6. Network manufacturers

In the past, the network manufacturers have been strongly vertically integrated, manufacturing their own key components to form systems that they fully understand. The optimistic projected growth rates for telecommunication traffic were not realised, reducing the income available to the network operators. This cost pressure fed through from the network operators, who purchase the equipment, and this has meant that the network manufacturers have had to drastically reduce costs. To achieve this, the component-manufacturing functions have been discarded, as they are not the core business.

These companies are benefiting from low-cost components developed under *Multi-Source Agreements* (MSA). Potentially, this allows different manufacturers' components to be used in various parts of the system.

6.7. Telecomms industry

The economics of the telecommunications industry has changed radically. The cost per bit reduces year on year. In the past, the rate of expansion of the network has been sufficiently high that overall finances were buoyant. However, the current situation is that installed capacity is not being fully used. As a consequence, the operators need to reduce costs by improving efficient system utilisation as the revenue per bit still reduces each year. This is now managed by lower cost-per-bit rather than by expansion.

Much of the existing telecommunications system is based on the *synchronous digital hierarchy* (SDH), which was introduced in the 1990s. Although significant effort was spent to develop systems operating at 40 Gb/s, the majority of the systems currently being installed operate at 10 Gb/s. In order to make efficient use of the networks and gain the benefits of convergence between data and voice, there is considerable effort to develop all *Internet Protocol* (IP)-based systems. In order to obtain good quality of service, stringent timing constraints (latency) are required for *Voice Over IP* (VoIP).

As telecommunications operators move into a truly broadband future, a major problem arises concerning the mismatch between the cost of providing bandwidth and the consequential growth in revenues. The economic model of the telecommunication sector is based on the premise that the transmission capacity is fully used. Although the purchase price of new equipment decreases rapidly as the technology becomes available from a greater number of vendors (e.g. >30% per year), the additional revenue that can be achieved exceeds this cost, over the lifetime of the system. Some of this additional earned value is passed back to the consumers in terms of a lower cost-per-bit per year. The fundamental problem is that if the rate of growth in the

demand is too high, the effective lifetime of the equipment is reduced i.e. the equipment becomes obsolete and must be replaced with a higher bandwidth system before the deployment costs are recovered[10]. Within the UK, predictions for 2006/7 of the number of broadband internet customers range from 6 to 10 million.

6.8. Standards committees and trade associations

There are a number of standards committees and trade associations that feed into the datacomms area. The work carried out by these committees ranges from consensus specification to detailed calibration and measurement techniques. Measurement specifications have been developed for a number of parameters (e.g. jitter) within different standards bodies. Because of slight differences in the way that systems operate, the approach taken by two standards bodies to measure the same parameters can be quite different. Details of the interrelations between standards bodies and trade associations is given in section 13.

Table 1 Standards committees

Title		Role-responsibility
ANSI	American National Standards Institute	Fibre Channel standards
IEC	International Electrotechnical Commission	TC86 fibre optics SC86A fibres & cables SC86B fibre optic interconnecting devices and passive components SC86C fibre optic systems and active devices
IEEE	Institute of Electrical and Electronic Engineers	Ethernet standards IEEE 802.3
ISO	The International Standards Organisation	7-layer model for network communication protocol
ITU	International telecommunications union	Subcommittees of interest SG4, jitter; SG 13, SG 15.

Table 2 Trade associations

Title		Role-responsibility
OIF	Optical internetworking forum	Development and deployment of interoperable products and services for data switching and routing using optical networking technologies
MEF	Metro Ethernet forum	Directed towards IEEE 802.3 standards
SNIA	Storage Network Industry Association	Storage Network Industry Association a Trade association for data storage. Also involved in local area networking. These industries are generally working to ANSI Fibre Channel standards.
XFP	www.xfpmsa.org/	Multi-source agreement between companies to develop a small form factor plugable transceiver operating at 10 Gb/s.

7. Technologies

7.1. 7-Layer model

The *International Standards Organisation* (ISO) defines a ***7-layer model*** for network communication protocol. The model is more formally called the *Open Systems Interconnection* (OSI) model and can be applied to any network (see section 14 for more detail). The advantage of breaking down the protocol into layers is twofold: Each layer can be regarded as a black box and communication need only take place at the layer appropriate for the task. This approach is generic and can be applied to telephone or data systems.

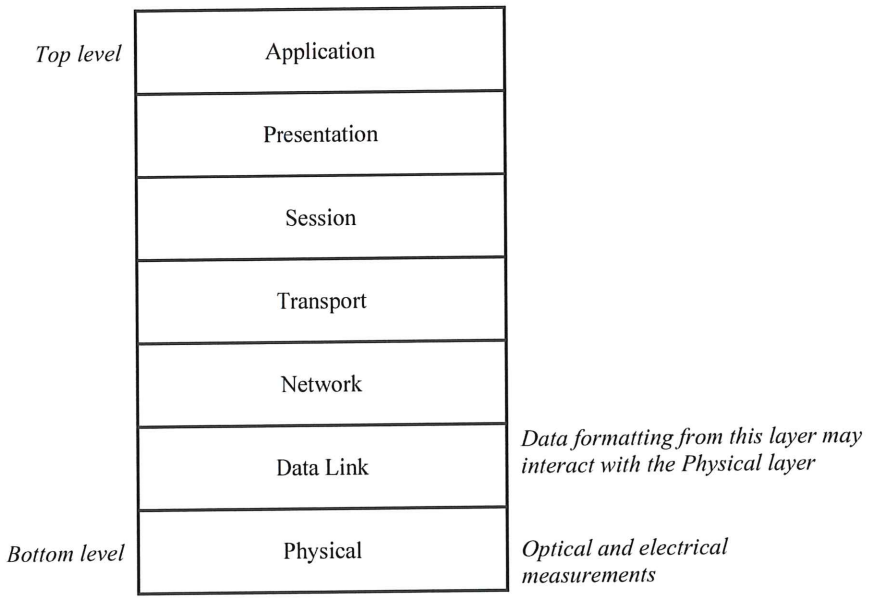


Figure 3 Open Systems Interconnection 7-layer model

7.2. Existing telephony system

Much of the existing telecommunications system is based on the *synchronous digital hierarchy* (SDH), which was introduced in the 1990s. Although significant effort was spent to develop systems operating at 40 Gb/s, the majority of the systems currently being installed operate at 10 Gb/s.

7.2.1. Wavelength division multiplexing

Wavelength division multiplexing (WDM) greatly expanded the capacity of the telecommunications system. It allows each fibre to carry a large number of channels typically spaced at 100 or 200 GHz and centred at 193.1 THz.

The majority of the transmission systems use the wavelength range 1528 nm to 1560 nm (C band). The pressure to increase capacity, lead to additional bands being specified and optical amplification technologies were developed based on Erbium and other rare earth elements, and also using stimulated Raman amplification within the transmission fibre. At present however, almost all systems are based on C-band EDFA technology, and component prices have dropped to make this a commodity product.

In order to reduce costs, a variation on the theme is *coarse wavelength division multiplexing* (CWDM). In this scheme, the channels are spaced at 6-7 nanometres. This allows uncooled lasers to be used reducing the component cost and all the attendant system overheads.

7.2.2. Convergence – strategic changes within the telecommunication system

The traditional telecommunications system set up a call as a complete end-to-end link. However, for speech a large fraction of the connection time contains no information. In order to make efficient use of the networks and gain the benefits of convergence between data and voice, there is considerable effort to develop all IP-based systems. In order to obtain good quality of service, stringent timing constraints (latency) are required for *Voice Over IP* (VoIP).

Ring architectures are typically used in Ethernet systems as they provide a robust network with a degree of protection against damage. The core of the telecommunications system also has a similar degree of protection. Star networks (as used in PON systems) are much less robust. A number of companies offer products, which convert data from IP-based systems to SDH and vice versa. Our interest in these systems would be limited to the optical to electrical interfaces only.

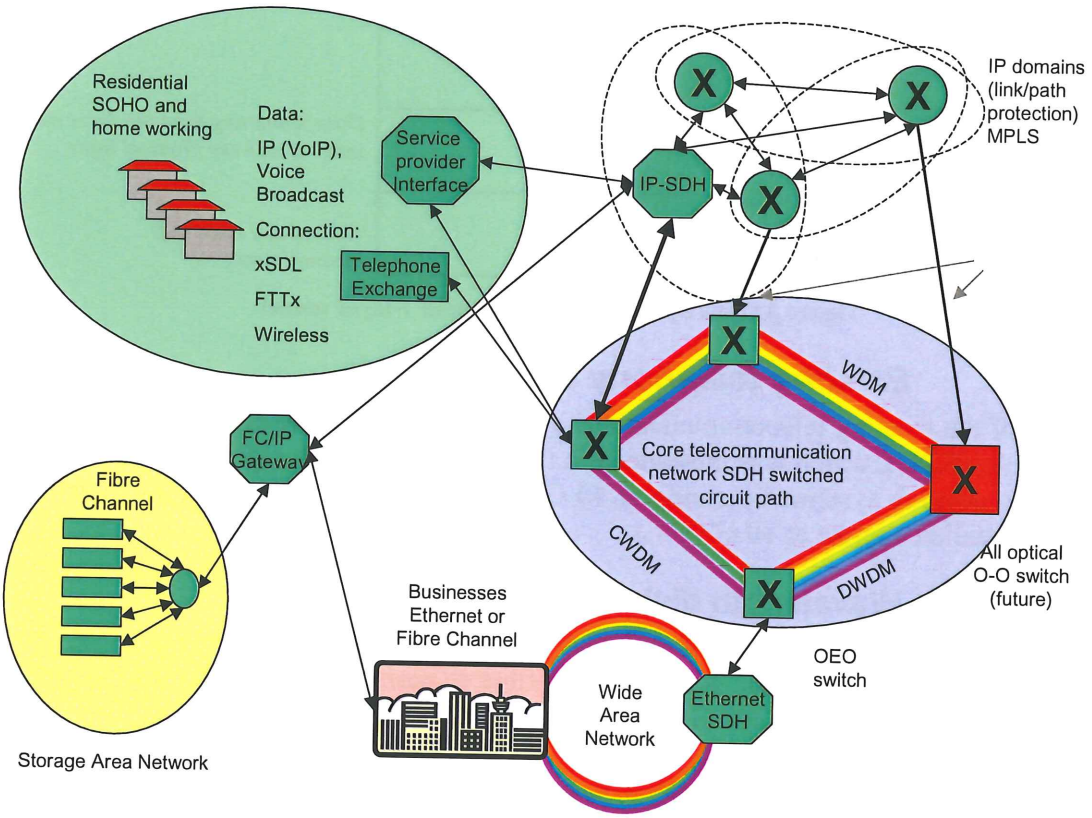


Figure 4 View of the network convergence process linking data and telecommunications. Interfaces for conversion between FC/IP and SDH are available. Voice over IP will improve the efficient utilisation of the network

Since the majority of the increase in the capacity of telecommunications system has been driven by data, it is reasonable to expect that systems will more closely resemble computer networks in the future.

7.3. Multi-Source Agreements for components

Driven by the changes in structure of the industry and with the aim of reducing costs a number of *Multi-Source Agreements* (MSA) have been reached between component manufacturers. Although the aim was to provide cost savings and interoperability there may be differences between similar products offered by different companies. There is a tension between the *'proprietary'* solutions, which may offer additional features, and the *'standardised'* solutions that offer lower costs. Interoperability is a key issue in this arena.

7.3.1. Design variation

In some agreements, only the optical and electrical interfaces are specified. This allows variants of the design to meet different market needs, for example 40-80 km or long-haul systems. The difference between these components is likely to be the use of *Electro-absorption* EA modulators as opposed to the more expensive $LiNbO_3$ Mach-Zehnder modulators.

SFP and XFP MSAs also specify parameters such as the physical size and power dissipation. However, the internal technology used to realise to components will differ from vendor to vendor. These components were designed to be small, simple and low-cost with data communications and Ethernet as the expected main business. In practice, because the potential reach of these systems is 40 km to 80 km, XFP components are also being used extensively in mainstream telecommunications markets.

7.3.2. Direct modulation of laser

Direct modulation of the laser can be used with data rates of up to 2.5 Gb/s. Above this data rate, the effects of chirp become significant and so separate modulation must be used. In the past, this has been based on external $LiNbO_3$ Mach-Zehnder modulators. EA modulators, integrated with the laser chip, offer a significant reduction in cost because of the reduced complexity of the packaging and alignment.

7.4. Fibre Channel

Fibre Channel (FC) [12] is a set of standards and technologies widely used in *Storage Area Network* (SAN), which is a network that connects various computer devices such as server, workstation, storage devices etc... FC has been developed to replace and extend the capabilities of the Small Computer System Interface (SCSI) developed in the 80's to interconnect storage devices. Two media used with FC are copper cable and optical fibre. The transmission distance is limited to 30 m with copper link but reaches 500 m with multimode fibres at 850 nm and up to 80 km with single mode fibre at 1550 nm. With optical fibre links FC can operate at 1, 2 and 4 Gb/s with 10 Gbits/s under development. The FC standards are being developed by the ANSI T11 technical committee. In Europe the trade association SNIA-Europe promotes the usage of FC as the standards of choice for SAN. MSAs have been set up by many

manufacturers to provide interoperability *Small Form Factor* (SFF) and *Small Form Factor Plugable* (SFP) optical transceiver to be used in FC systems.

7.5. Jitter and stressed-eye

Two common definitions of jitter are: "Jitter is defined as the short-term variations of a digital signal's significant instants from their ideal positions in time. Significant instants could be (for example) the optimum sampling instants" (SONET)[11] and "The deviation from the ideal timing of an event. The reference event is the differential zero crossing for electrical signals and the nominal receiver threshold power level for optical systems" (Fibre Channel)[12]. Although there are differences in these two (and many other) definitions, it is important to focus on the fundamental similarity, which is that jitter has to do with the time difference between the ideal and actual occurrence of an event. The event in question may change, depending on the application. It could be, for example, the rising or falling edge of a clock, the optimum sampling instant of an NRZ encoded waveform, the differential zero crossing, or something else; but *jitter is simply the time difference between when a pre-defined event should have occurred and when it actually did occur.*

Jitter is playing an increasingly important role in today's high-speed digital communication systems. For example, SONET specifies that an optical transceiver has no more than 10 mUI RMS random jitter (1UI = 1 Unit Interval = 1 bit period). This would mean for a 10 Gb/s system, the random jitter must be less than or equal to 1ps RMS. In order to meet the 10mUI RMS requirement in a 10 Gb/s transmitter, each device in the transmitter must contribute significantly less than 10mUI RMS. However, the peak-to-peak (p-p) jitter is important as it determines the likelihood of generating an error. From a statistical perspective, it is important to associate peak-to-peak jitter with a quality of service (e.g. $1{:}10^{-12}$ BER) and a *probability density function* (PDF) distribution (e.g. Gaussian), otherwise it is difficult to make quantifiable predictions. Measurements of this sort on an oscilloscope become problematic because the number of sampling points will be much less than the quality of service target and the measurement jitter of the oscilloscope may be larger than the jitter contributed by the DUT (device under test).

Jitter can be divided into two fundamental types, called random jitter and deterministic jitter. *Random jitter* (RJ) is unpredictable and has a Gaussian PDF. *Deterministic jitter* (DJ) is predictable (assuming prior knowledge of the bit stream characteristics) and has definite amplitude limits (i.e., it is *bounded*). RJ is caused by thermal (or other random) noise effects that are induced into the phase of the clock and data signals in the system. DJ is caused by process or component interactions in the system, such as the effect of limited bandwidth on specific patterns of 1's and 0's in the bit stream.

The use of the deliberately distorted optical signal 'stressed-eye' to determine the performance of an optical receiver has been proposed as part of the IEEE Ethernet standards. Some reported experimental results show quite severe degradation of the receiver response[13], raising some questions about the technique. This is possibly an area where measurement support of consensus standards would be valuable.

7.6. Material systems

The property required for light emitting semiconductor materials is that they should be a 'direct-gap' material. This means that an electron can be excited to or emitted from an upper energy-state without requirement for an additional lattice-vibration phonon to complete the process. The difficulty however is that silicon is a indirect-gap material (requiring the additional phonon to complete the transition), whereas Gallium Arsenide (GaAs 850 nm), Indium Phosphide and Indium Gallium Arsenide Phosphide (InGaAsP covering 1300-1650 nm) are all direct-gap materials that can be used directly to create lasers and light emitting diodes. Also, the spacing of the atoms in a crystal (lattice constant) is different for each material, implying that you can only grow certain material systems together e.g. GaAlAs will grow on GaAs but GaAlAs will not grow on InP because the lattice constant is different. At present, the majority of the optoelectronic devices are grown using the InGaAs/InP material system. InP is also used extensively for microwave and millimetre-wave active components.

There is considerable research effort at Intel to develop silicon as a material to product cheap photonic devices[14]. Silicon has the advantage of excellent mechanical and engineering properties in addition to its qualities as a semiconductor material. The idea is to utilise the widely used and reliable silicon based manufacturing processes for integrated electronic devices to construct integrated photonic components. The ultimate aim is to build and passively align the different optical parts of a transceiver (laser, tuneable filter, modulator and receiver) as well as the CMOS controlled circuitry on the same silicon wafer. Intel has announced recent results using silicon photonics[14]. These include the development of a silicon-based modulator with a 1 GHz bandwidth and commercial devices based on silicon light emitting devices[15].

7.7. Links between computer boards

Optical interconnect technology, in the form of fibre optics, has been used for decades in long-distance applications, such as telephony and wide area networks, and in recent years has made inroads into shorter-distance applications, such as communications between servers in a data centre. Because of increased processor speeds, more bandwidth is needed in the data bus to interconnect chips and board inside a computer. To address this problem Intel is currently undertaking research to replace copper based bus connection by an optical bus[16]. Optical interconnects are showing promise for these ultra-short-reach applications because of their ability to support far higher bandwidth than the metal wires that now carry data from board to board, chip to chip, and even within a single chip.

While still some years from viability in a production environment, the technology has been demonstrated by a team from the Intel Components Research Lab in a fully functioning prototype device that attained an aggregate bandwidth of more than 8 giga-transfers per second[17]. The technologies used by Intel are based on an array of VSCELs emitting at 850 nm, an array of GaAs photodiodes as receivers and polymer waveguides as a link.

Optical interconnect technology could begin to play a significant role by the middle of this decade. Around 2006 or 2007 (within the lifetime of this programme), Intel expect to see commercial-level optical interconnect technology at the board-to-board

level, and sometime in the 2010s at the chip-to-chip level. Because of the long timescale associated with this work, this area of research can be considered to be beyond the scope of the current project.

8. Study findings

In Datacommunications, three groupings can be defined by their endpoints. These are:

- Fibre to the home/premises. A growth area, but investment lags in the UK. Keeping transponder costs sufficiently low is a key issue in this area as there are other competing technologies.
- Fibre channel/computer/storage area networks/installers. Many manufacturers using this technology are U.S.-based. The systems currently operate at data rates of 1-4 Gb/s using multimode fibre and a short wavelength (850 nm). In this environment cost is an important issue.
- Core transport datacomms and telecomms. There is convergence of the two systems as IP is being increasingly adopted. There is also synergy with fibre to the home with the possibility of reducing costs in the longer term.

8.1. Issues specific to several technologies

There are a number of issues that span these different technologies:

- Bit-error and system reliability are determined in terms of 'stressed-eye' measurements within the Ethernet community and Jitter and noise/Q-factor within the telecommunications environment. The specific difficulty is that the measurement uncertainty and reproducibility of the measurements may be as high as 30 mUI in a 100 mUI budget at 10 Gb/s. This leads to issues of tolerancing and quality control during manufacture. The Government's Foresight studies suggest policies must be formulated to achieve internationally agreed open standards in electronics, computing and telecommunications[7]. BER measurement requirements were reviewed in the 1997 - 2000 Electrical Programme but at that time, the NMS did not invest in supporting the large datacomms industry with practical measurement solutions and formal traceability.
- The change in the component market, currently feeding core transport and optical networks used for data storage markets, is the range of components developed under multi-source agreements. There are two issues: interoperability within a single component class such as XFP and compatibility between different specifications. In the latter case for example, the value of the decision point may be fixed at 50% level in a low-cost transponder but may be optimised in a more sophisticated unit.
- The quality of the electrical waveform entering the transponder is often specified in terms of a worst-case level of degradation. This may be the equivalent of transmitting a signal over a stripline circuit path of up to 300 mm[18], to allow for routing and placement of components on a circuit board. Furthermore, the input impedance of the transponder may be nonlinear as this is an active digital circuit.
- Within the data communication networks the low-cost transmitters are being used for 40 km to 80 km spans. These distances are also specified within Fibre Channel. As a consequence, chromatic dispersion within the optical

fibre is important and so controlling the time/wavelength profile of the optical data (chirp) is particularly important as the components may be sourced from more than one vendor.

8.2. Technology specific issues

8.2.1. Fibre to the home/premises

To minimise the deployment costs, both active and passive optical networks use several different wavelengths for upstream (from the subscriber) and downstream (from the supplier) communications so that a single optical fibre can be used to carry the signals in both directions.

Passive optical networks have the additional difficulty that the upstream communications operate using *time-division multiplexing* (TDM) to interleave data from the individual subscribers. The signals from each of the separate premises must be timed to arrive at the receiver within a set time window so that they do not overlap with data from another customer. This leads to the difficulty, that the downstream communication is only initiated when the system receives a trigger signal. The mark-space ratio of the returned signal prior to the splitter will be low (1:32 or 1:1024). As a consequence, optical power measurement instruments have to be accurate at several wavelengths and have the capability for measuring peak optical power accurately.

8.2.2. Fibre Channel

The Fibre Channel specification includes the use of multimode optical fibre and short wavelength (850 nm). The difficulty with multimode optical fibre is that the transmission performance is often very dependent on the launch conditions. Within the system, the performance may also depend on the number of connections and the tightness of bends within the deployment. While it is quite possible to make laboratory-based measurements of the fibre properties, it may be difficult to apply these results in a meaningful way to a system.

8.3. Standards committees and trade associations

There are a number of standards committees and trade associations that support datacomms. The work carried out by these committees ranges from consensus specification to detailed calibration and measurement techniques. Although from the business perspective there is always a certain degree of political manoeuvring occurring within standards committees, it is believed that the key metrological issues will often surface in the committees. Contribution in this point could lead to significant impact.

9. Recommendations

9.1. Areas where NPL can contribute

NPL, as part of the UK NMS, has developed a unique range of measurements capabilities for optical telecommunications within the Photonics and Electrical programmes. Also, within the Electrical programme, existing and current work to develop and maintain traceable standards for electrical rise-time and for the accurate calibration of optical reference receivers underpins this activity.

Primarily our expertise lies with physical measurement and through traceable access to standards. In terms of the OSI model (Figure 3), this restricts the scope to within the physical layer (1). However, the way in which the data is formatted for transmission (layers 2 and 3) can have direct effect on the transmitted signal. An example of this problem is pattern dependent jitter. As the complexity of the systems increase to make the maximum use of available bandwidth, it is likely that more of these interactions will become apparent.

9.2. Measurement capabilities and synergy

A key theme within this project is the accurate characterisation of optical waveforms and optoelectronic devices. Consequently, this project is underpinned by work currently in progress within the Electrical Programme (Theme 6) and by access to the measurement capabilities for optical fibre and instrumentation developed in previous programmes (Photonics Programme Project 2.1). Also, one of the outputs of the project is accurate measurement data that will provide a quantifiable input to the network-modelling project (Photonics Programme Project 2.4). The interrelationships between this project, Electrical Programme (Theme 6) and other Photonics and EC projects are shown in Figure 5.

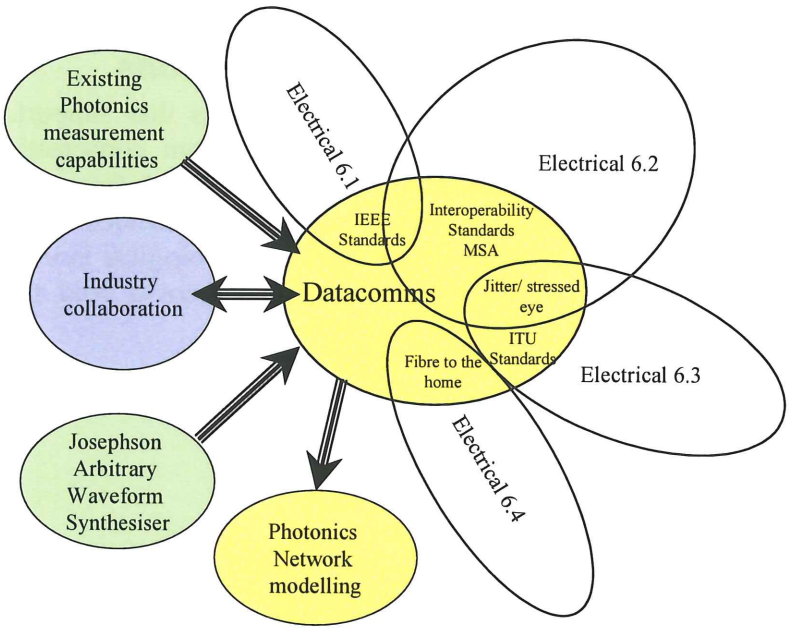


Figure 5 Interrelationships between projects

9.2.1. Electrical Programme Theme 6

Theme 6, within the electrical programme, provides the metrological support for electrical risetime measurements, data communications and RF measurements for wireless communications applications. The projects within this theme are listed in Table 3. During the formulation of this programme, it was noted that this work would provide key underpinning, but not overlap with the optical datacomms project.

Table 3 Projects within the electrical programme theme 6

Project	Description
1	Standards for electrical pulse measurement
2	Development of standards for electrical pulse measurement
3	Measurement standards for digital communication (datacomms)
4	Application of time domain techniques to RF and Microwave metrology

The total worldwide oscilloscope market is expected to grow to £1Bn by 2004. The area is seen to be growing in importance, particularly in the fields of telecommunications, data communications and computing. Work in the previous programme (2000 – 2003) has already allowed industry to improve the specification of instruments through the reduction of uncertainty. Dissemination of the risetime calibration work has large, UKAS accredited, fan-out within industry. The NMS has developed electrical risetime research and calibration facilities (11 ps pulse generator and 7 ps oscilloscope) that lead those in Europe. The facility uses novel optoelectronic techniques both to generate and sample short electrical pulses in the time domain. Other important aspects of the work include deconvolution with filtering, the characterisation of coplanar-coaxial transitions, and the measurement of jitter.

This work also significantly underpins other projects, including power for digital communications, data communications, optical and time domain network analysis and UWB measurements.

9.2.1.1. Key objectives within this theme

The broad sweep of interrelationships between the Datacomms and Electrical Theme 6 projects are shown within Figure 5. The key objectives and deliverables for this theme had been listed together with the project number in Table 4.

Table 4 Objectives within Theme 6

Project	Objective	Description
1	3	To input to IEC TC 85 standards deliberations on new risetime standard based on IEEE 181- 2003
2	2	Research and implement techniques to provide time and frequency domain facility for >75 GHz electrical sampling oscilloscopes, reference receivers and photodiodes
2	3	Research and implement techniques to characterise >4 GHz real-time oscilloscopes in the time and frequency domains, including requirements for underpinning RF and microwave areas.
3	1	To relate EVM, CCDF, SNR and Q-factor measurements - widely used in the data communications (datacomms) industry - to system performance
3	2	To validate jitter and wander measurement techniques for high-speed datacomms systems (e.g. SDH/SONET, W-CDMA, wireless LAN (WLAN), Gigabit Ethernet)
3	3	To input measurement techniques and standards to appropriate ITU/IEC/IEEE committees
4	1	To research and implement techniques to provide power/time template standards for digital communications systems.

Many of the objectives within the electrical theme provide key underpinning support for the datacomms work. Q-factor (project 3 objective 1) is used as a figure of merit in both electrical and RF communications.

The work on jitter within the electrical theme (project 3, objective 2) is restricted to SDH and wireless, whereas the datacomms applications extend to a variety of different coding schemes.

By combining the efforts of the Photonics (datacomms) and Electrical (Theme 6) programmes, the work of standards bodies such as the ITU can be more effectively covered. There is no duplication of effort because the topics covered by the standards committees feed into both programmes.

There is synergy between the peak power issues that will arise in the fibre to the home environment and the measurement techniques that will be developed for the RF power/envelope measurements. In both cases, the signal comprises of a modulated carrier and so the signal (envelope) value can never be negative. There is relation between this work and the risetime and pulse definitions of the carried out within IEEE 181-2003 standards committee.

9.3. *Relevant work within current and recent projects*

Pre-existing work with in electrical theme 6 and other NMS and EU projects provides the datacomms work with a running start.

9.3.1. Progress towards accurate jitter measurement in the Electrical Programme Theme 6

NPL worked closely in collaboration with industry to evaluate the measurement techniques proposed in the appendices VII and VIII of the ITU document O.172.

We have developed a measurement technique that significantly reduces the instrumentation trigger jitter as shown in Figure 6 and Figure 7. Data jitter can be separated from the instrumentation jitter component.

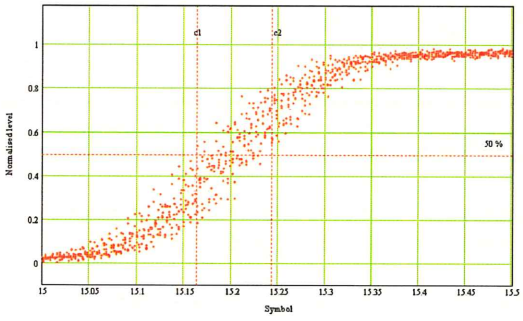


Figure 6 Rising edge without timebase jitter compensation 79 mUI p-p at 9.953 Gb/s (7.9 ps)

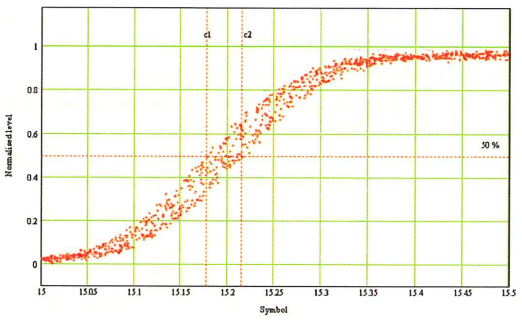


Figure 7 Rising edge with timebase jitter compensation 38 mUI p-p at 9.953 Gb/s (3.8 ps)

Certain manufacturers' instrumentation may include a similar system, realised in hardware. Where these systems are present there is no significant improvement to be gained by adopting this technique.

The performance of optical re-timing scheme that reduces the effect of jitter has been assessed and the accuracy improvement of the edge transition is typically at least a factor of four. The degree of improvement is affected by the quality of the underlying, un-retimed signal.

This work showed that the jitter could not be completely removed but the considerably reduced. It is expected that this work would form the basis for future work on jitter and stressed-eye measurements within the Datacomms Project.

9.3.2. Waveform metrology Electrical Programme Theme 6

The waveform metrology work, started within Electrical Programme Theme 6, will support work in the Datacomms Project. Considerable progress has been made in this area of the project within the last year. Techniques have been developed to measure the vector optical response of a reference receiver accurately in the frequency domain at up to 76 GHz[19]. The scalar optical response of the reference receiver can be measured at up to >120 GHz. In the time domain, measurements are limited by jitter, as the optical impulse available from the measurement system is <200 fs.

The optical receiver is a key tool to measure many of the parameters required for datacomms. Accurate and traceable calibration of this instrument will provide a strong underpinning for all measurements made within the project.

9.3.3. Josephson Arbitrary Waveform Synthesiser (JAWS)

JAWS is a European research project funded by the EU as part of the FP 5, under contract no. G6RD-CT 2001-00599, that comprises of six partners from EU member states. This project was completed in November 2004.

The main technological objective of the JAWS project was to build an operational *Josephson Arbitrary Waveform Synthesizer* (JAWS) for generation and calibration of arbitrary waveforms and of root-mean-square values in the regime of low frequency and low voltage signals[20]. The key aspect of this project was that it used 10 Gb/s data communications components to generate a 5 Gb/s RZ data stream.

The benefit of this project to the current work is that it gave us some exposure to commercial transponder components. One important issue in the JAWS project was to ensure that the optical pulses were consistent in terms of the optical height and width. This research has provided us with valuable insights for the development of the high-quality optical data streams that would be required for ultra-low jitter transmitters and stressed-eye measurements.

9.3.4. Laser wavefront sensing project

An objective of this project (Photonics programme project 1.3) is to support the establishment of the free space optics communication technology by establishing a new calibration service of laser test instrumentation for optical peak powers of pulsed sources and demonstrating the international equivalence of UK laser power measurements through an international comparison of optical peak power. There is some synergy between this project and the optical power measurement requirements of a FTTx PON environment.

9.4. Planned research areas

The choice and order of the research should reflect the potential impact and the timeliness of the industrial requirement. In order to maximise the impact, we would be keen to work in collaboration with industrial companies, standards bodies or trade associations to ensure focus. The key areas that have been identified are:

- Optical waveform related measurements. This provides active support for measurements of jitter and allows impartial investigation of interoperability between component vendors. Depending on resources, this could be extended to provide validated stressed-eye measurements and an underpinning for dispersion penalty. The degradation of electrical waveforms used to drive transponders may also need to be measured.
- Fibre Channel operating at 850 nm and using multimode fibre has very different requirements in terms of wavelengths and fibre type. Optical fibre bandwidth measurement techniques will be developed under the 'Measurements for Broadband Access' project (2.3).
- Fibre to the home/Fibre to the premises is currently showing strong growth in the USA and Japan. The rapid uptake of broadband within the UK suggests that work in this area may be relevant within the lifetime of this programme. Live network trials of PON systems will take place in the UK over the next year. These systems will need to be low-cost but also have complex metrological issues.
- Contribution to standards bodies. It is anticipated that many measurement related issues would be raised and agreed upon within these committees. If we are able to contribute in this area we may be able to provide more timely solutions for industry.
- One of the outputs of this project would be to provide accurate information for the NMS project Modelling and Measurements for Optical Networks project (2.4).

10. Project planning

10.1. Specific tasks

A number of specific tasks have been identified for this project:

- Evaluate different mechanisms for generating high-quality optical data streams. The ultimate aim should be to control the degradation of a data pattern either by adding jitter or by distorting the eye. Relates to jitter, stressed-eye, Q-factor and polarisation effects.
- Design and evaluate a system to measure the change in optical frequency during the evolution of a data pulse. This will support dispersion penalty and chirp measurements.
- Procure and evaluate XFP and other MSA transponders. If it is possible to obtain work in collaboration with the manufacturers and obtain components on loan this will allow us to evaluate a wider range of products. Depending on the sensitivity of the material this may need to be reported in a restricted manner.
- Fibre Channel. Multimode fibre measurement support will be provided as part of the project. Whilst we have low repetition rate (100MHz) optical sources at 900 nm, it is not clear that these will operate successfully with a low-cost datacomms transceiver. However, it should be relatively simple to calibrate an optical receiver to measure the signals generated by the laser transmitters. Some support for 850 nm transponders may be possible but the priority will be set by industry demand. It is planned to investigate modal launch and bandwidth under Project 2.3.
- Contribute to ITU-T. SG. 4 (jitter) and ITU-T. SG. 15 (transport). If we can get access to any of the more datacomms related committees either directly or through industrial partners this should be attempted. It is anticipated that much of this work will take place outside the committee forum and some supporting measurements may be required.
- Passive optical network systems are expected to use multiple wavelengths and different services and timed division multiplexing for the uplink. Accurate measurement of the uplink optical power will require time resolved measurements. Also, the measurement of OTDR dynamic range and low-level signals will be important.

10.2. Priority and Sequencing

The accurate measurement of optical waveforms should be carried out early in the project as it underpins interoperability testing and more complex measurements such as chirp/dispersion penalty, jitter and stressed-eye.

Work on Fibre to the home/premises should be timed to be in line with developments in the UK. With this in mind, it is anticipated that the work will be required towards the end of the project. Consequently, work in this area should be timed to start in 2005.

Contribution to standards committees is an ongoing task throughout the lifetime of the project. It is anticipated that specific areas, such as jitter, may be completed early in this project. The profile of the standards committee work is likely to change during the lifetime of the project.

11. Glossary

Acronym	Definition
ADSL	Asymmetric Digital Subscriber Line
ANSI	American National Standards Institute
ASCII	American Standard Code for Information Interchange
BER	Bit Error Rate
CCDF	Complementary Cumulative Distribution Function
CMOS	Complementary Metal Oxide Semiconductor
CWDM	Coarse Wavelength Division Multiplexing
DJ	Deterministic Jitter
EA	Electro-Absorption
EBCDIC	Extended Binary Coded Decimal Interchange Code
EDFA	Erbium Doped Fibre Amplifier
EIA/TIA	Electronic Industries Alliances / Telecommunications Industry Association
EVM	Error Vector Magnitude
FC	Fibre Channel
FTTx	Fibre To The Home/ Premises (FTTH/FTTP)
Gb/s	Gigabits per second (data rate)
GbE	Giga bit Ethernet
IC	Integrated Circuit
ICT	Information and Communication Technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
INCITS	InterNational Committee for Information Technology Standards
IP	Internet Protocol
ISO	International Standards Organisation
ITU	International Telecommunications Union
JAWS	Josephson Arbitrary Waveform Synthesizer
MEF	Metro Ethernet Forum
MSA	Multi Source Agreement
NMS	National Measurement System
NRZ	Non Return to Zero
OIF	Optical Internetworking Forum
OSI	Open Systems Interconnection
OSNR	Optical Signal to Noise Ratio
OTDR	Optical Time Domain Reflectometer
PDF	Probability Density Function
PON	Passive Optical Network
RAID	Redundant Array of Independent Disks
RJ	Random Jitter
SAN	Storage Area Network
SCSI	Small Computer System Interface
SDH	Synchronous Digital Hierarchy
SFF	Small Form Factor
SFP	Small Form Factor Plugable
SNIA	Storage Network Industry Association
SNR	Signal to Noise Ratio
SONET	Synchronous Optical Network
TDM	Time Division Multiplexing
VoIP	Voice Over IP
VSCEL	Vertical Cavity Surface Emitting Laser
WDM	Wavelength Division Multiplexing
WLAN	Wireless Local Area Network
XFP	10 Gigabit Small Form Factor Pluggable

12. Contacts

The companies contacted for the writing of this report are listed in Table 5. This list is not exhaustive, as some companies have preferred to not be cited.

Table 5 Companies contacted

Agilent	ITU-T SG15
Amplicon	Marconi Communications
Anritsu	Maxim HF/Fibre Communications
Bookham Technology	Metro Ethernet Forum
Cisco	PerkinElmer Optoelectronics
EXFO	Storage Network Industry Association
Fujitsu Telecommunication	University of Essex
LA Technologies	University of Warwick

13. Standards committees and trade associations

13.1. ITU-T

The ITU Telecommunication Standardisation Sector (ITU-T) is one of the three sectors of the *International Telecommunication Union* (ITU), which is based in Geneva, Switzerland. The ITU-T produces standards (named Recommendations) covering all fields of telecommunications. The ITU-T is divided into technical subcommittees named Study Groups (SG), which address technical problems in a particular area of telecommunication standardisation. The individual workpackages investigated by a Study Group are known as 'Study Questions'.

For this project the subcommittees of interest are the Study Group SG4 (Telecommunication management, including TMN), SG 13 (Multi-protocol and IP-based networks and their internetworking) and SG 15 (Optical and other transport networks). More information can be found at http://www.itu.int/home/index.html

13.2. ANSI

The *American National Standards Institute* (ANSI) is an American organisation that coordinates many US standardisation groups and publishes standards. Two of these groups have produced relevant standards for this project: T11 and EIA/TIA.

The T11 technical committee (which belongs to the *International Committee for Information Technology Standards* (INCITS) is the organisation that produces the standard for Fibre Channel.

The *Electronic Industries Alliances* (EIA) *and the Telecommunications Industry Association* (TIA) are two US trade associations that produce in cooperation standards for datacomms.

13.3. IEC

The *International Electrotechnical Commission* (IEC) is a global organization that prepares and publishes international standards for all electrical, electronic and related technologies. It is divided into several Technical committees (TC). The TC relevant to this project is the TC86 that works on the development of fibre optic standards. This TC is also divided into three subcommittees (SC 86A: Fibres and Cables, SC 86B: Fibre Optic Interconnecting Devices and Passive Components, SC 86C: Fibre Optic Systems and Active Devices) and each of them separates the work into different Working Group (WG).

13.4. IEEE-SA

IEEE-SA stands for *Institute of Electrical and Electronic Engineers Standard Association*. It is an international organization that produces industry standards. Two key areas where the IEEE are active;

- Standard for Ethernet IEEE 802.3 CSMA/CD
- Definition of electrical pulses and risetime IEEE 181-2003

13.5. OIF

The *Optical Internetworking Forum* (OIF) encourages the development of interoperable products and service for datacomms products. It publishes optical internetworking specifications drawn from international standards. The OIF is divided into several working groups that work in different areas and published interoperable specifications. More information can be found at http://www.oiforum.com/

13.6. MEF

The *Metro Ethernet Forum* (MEF) is an organisation with the mission of accelerating the adoption of optical Ethernet as the technology of choice in metro networks. Outputs from this organisation are white papers, implementation agreements between MEF members, test procedures, and technical specifications and recommendations to other standards bodies. More information can be found at http://www.metroethernetforum.org/

13.7. SNIA- Europe

The *Storage Network Industry Association* (SNIA) is a Trade association for data storage and local area networking companies. These industries are generally working to T11/ANSI Fibre Channel standards and interoperability agreements.

13.8. XFP

The XFP "10 Gigabit Small Form-Factor Plugable" group has developed a Multi-Source Agreement for a next generation optical transceiver. Specifications of this MSA include a module, cage hardware, and IC interfaces for a 10 Gbit hot-plugable module, converting serial electrical and optical signals to external serial optical and electrical signals. The technology is intended to be flexible enough to support OC192/STM-64, 10 G Fibre Channel, G.709, and 10 G Ethernet, usually with the same module. The module design and the volume of production are expected to enable very low cost 10 Gb/s solutions. More information can be found at http://www.xfpmsa.org .

XFP Applications:

- OC192/STM-64 9.95 Gb/s
- 10 Gigabit FC 10.5 Gb/s
- G.709 10.7 Gb/s
- 10 Gigabit Ethernet 10.3 Gb/s
- Smaller space and lower cost alternative to parallel-optics VSR

XFP Value Propositions

- Protocol Agnostic - "any application, any rate".
- Allows 16 XCVRs on a typical 19" rack with 23mm pitch density.
- Single footprint for all links.
- Less than 1/3 the power and size of an MSA with parallel interface.
- Hot-plugable.

XFI (10 Gigabit Serial Electrical Interface) Electrical Signalling

- Supports 12" (300 mm) of FR4 with one connector
- Low EMI and power due to nominal 500 mV differential drive.

- Slew control for improved Signal Integrity and lower EMI.
- TX and RX signals each are a 100 Ω differential pair, AC coupled for simplicity.

13.9. Small Form Factor (SFF) and Small Form Factor Plugable (SFP)

The SFF and SFP are two industry agreements for fibre optic transceiver modules in support of standards for fibre optic systems such as Fibre Channel, Gigabit Ethernet and SONET/SDH applications. The main difference is that one design is plugable (SFP) and the other (SFF) is soldered directly to a board. As with the XFP MSA the agreements specify the physical, electrical and optical interfaces. The internal design of the transceivers is not covered by the agreement and can differ between manufacturers but the electrical and optical specifications must be compatible with those enumerated in the appropriate standards. For more information see http://www.sffcommittee.org.

13.10. Summary of differences

The key differences between SFF, SFP and XFP are summarised in Table 6. The key difference is that the SFP/SFF transponders will operate over a variety of data rates but the XFP transponders are designed only to cover the 10 Gb/s standards. Others transceivers exist but are not cover by this report. See http://www.schelto.com/ for example for more information.

Table 6 Key differences between transponders

Parameter	Technology		
	SFF	SFP	XFP
Plugable		●	●
Gigabit Ethernet	●	●	
Fast Ethernet	●	●	
10G Ethernet			●
1x\2x\4x Fibre Channel	●	●	
8x Fibre Channel		○	
10x Fibre Channel		○	●
OC-3/STM-1 (140 Mb/s)	●	●	
OC12/STM-4 (622 Mb/s)	●	●	
OC48/STM-16 (2.5 Gb/s)	●	●	
OC192/STM-256 (10 Gb/s)			●
850 nm	●	●	●
1300 nm	●	●	●
1550 nm	●	●	●
50/125 μm and 62.5/125 μm multimode fibre	●	●	● (300 m)
9/125 μm single-mode fibre	●	●	● 40 km to 80 km

○: under development / discussion

13.11. Interaction between standard committees, trade associations and standards

The interaction between the standard committees (IEC, ITU-T…), trade associations (MEF, OIF…) and standards (for SONET, SDH, Fibre Channel…) is displayed in Figure 8. In this figure, the blue arrows indicate the standards that the standard bodies specify. The red arrows show the links that exits between the standards (it can be seen that the FC and GbE standards interact each other and the SONET/SDH/OTN standards are reference for the FC and GbE) and between the standards and the trade associations (for instance the FC standards are used by OIF to produce their interoperable agreements). The green arrow indicates the collaboration that trade associations have with the standard committees.

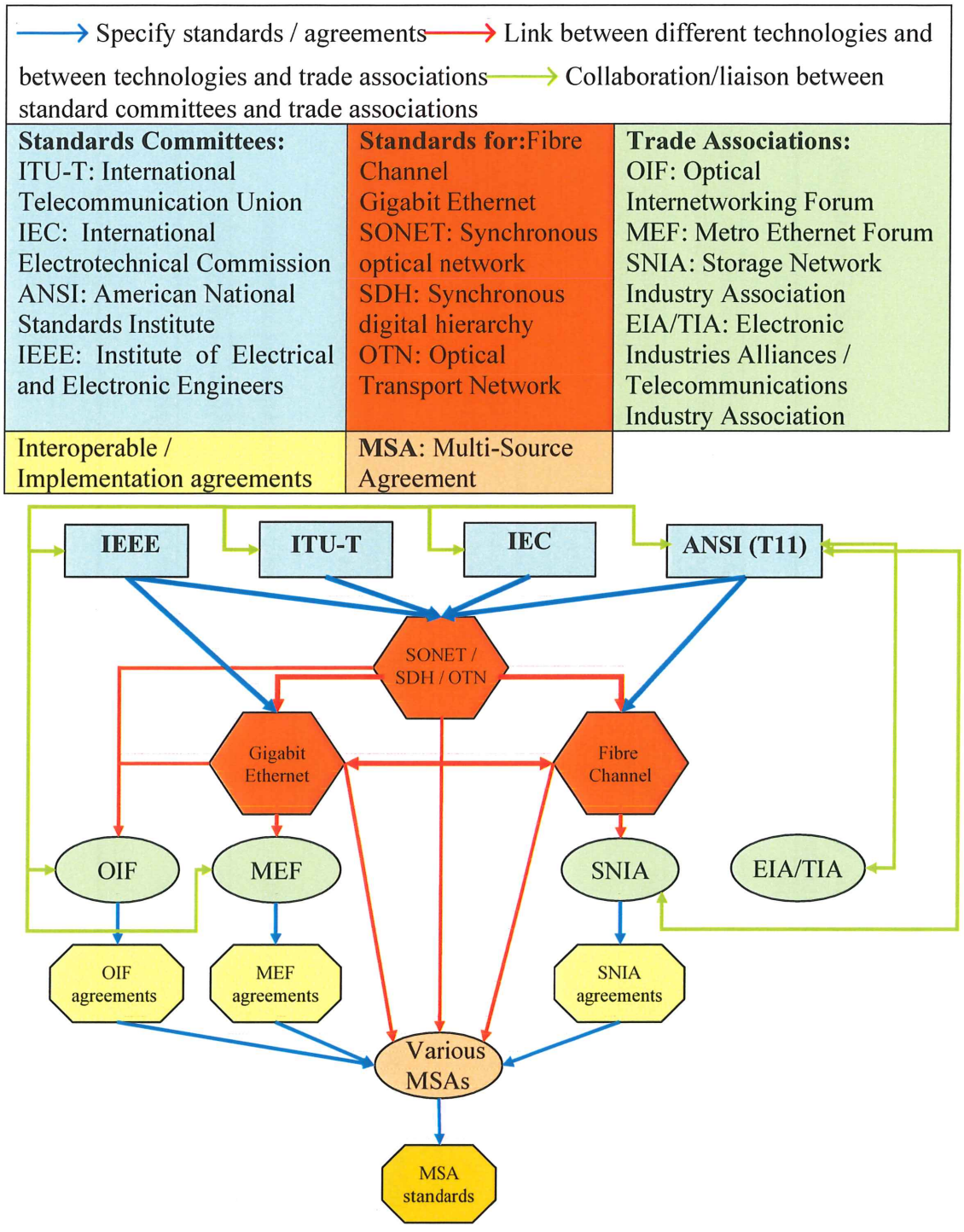


Figure 8 Interaction between standard committees, trade associations and standards

13.12. Overlap and linkage between technical standards

A number of the parameters of interest for the datacomms industries are listed in this annex. A list of standard documents is given for each parameter. A list of cross-references is also given for each standard document.

Measurements	Technology	Standard Committees	Document Name	Date	Cross Reference	Title
Chirp & alpha measurement		IEC TC86C	86C/609/CDV IEC 61280-2-10 Ed 1	2004	ITU-T G.691	Fibre optic communication subsystem test procedures - Part 2-10 Digital systems - Time-resolved chirp and alpha-factor measurement of laser transmitters
Extinction ratio	1 GbE	IEEE	IEEE std 802.3-2002	2003	ANSI/EIA/TIA-526-4A-1997	IEEE Standard for Information technology--Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific requirements--Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications / Section 3 / Paragraph 38.6
	10 GbE		IEEE std 802.3ae-2002	2002		IEEE Standard for Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications-Media Access Control (MAC) Parameters, Physical Layer and Management Parameters for 10 Gb/s Operation / Paragraph 52.9
	Any	IEC TC86C	86C/577/CDV IEC 61280-2-2 Ed 2.0	2003	IEC (60825-1, 61281-1, 61282-1) / ITU-T G.691, G.957 / TIA/EIA-526-4A / EIA/TIA-559	FIBRE OPTIC COMMUNICATION SUBSYSTEM TEST PROCEDURES – Part 2-2- Digital systems – Optical eye pattern, waveform, and extinction ratio measurement
		TIA/EIA	TIA/EIA-526-4A: OFSTP4	1997		Optical Eye Pattern Measurement Procedure
Eye pattern	Any	TIA/EIA	TIA/EIA-526-4A: OFSTP4	1997		Optical Eye Pattern Measurement Procedure
Jitter	10 GFC	T11 / ANSI	T11/ANSI/NCITS 364-2002	2002	IEEE std 802.3ae-2002 / ITU-T 0.172, 1999 / NCITS TR-25:1999	Fibre Channel 10 Gigabit

Measurements	Technology	Standard Committees	Document Name	Date	Cross Reference	Title
	FC	T11.2 / ANSI	T11.2 / ANSI/FC-MJSQ	2004		Fibre Channel- Methodologies for Jitter and Signal Quality Specification
			T11.2 / ANSI FC-PI-2	2004	FC-MJSQ	Fibre Channel- Physical Interfaces - 2
	SDH	ITU-T	ITU-T O.172	2001	ITU (T:G.691, G.703, G.707/Y1322, G.772, G.783, G.810, G.811, G.812, G.813, G.823, G.824, G.825, G.957, G.958, O.3, O.150, O.171, O.181, R: F.750-3), ANSI T1.105.03 (1994), ANSI T1.105.06 (1996)	Jitter and wander measuring equipment for digital systems which are based on the synchronous digital hierarchy (SDH)
	OTN	ITU-T	ITU-T O.173	2003	ITU-T O.172, ITU-T (G.703, G.709/Y.1331, G.810, G.8251, G.959.1)	Jitter measuring equipment for digital systems which are based on the Optical Transport Network (OTN)
	Any	IEC TC86C	86C/577/CDV IEC 61280-2-2 Ed 2.0	2003	IEC (60825-1, 61281-1, 61282-1) / ITU-T G.691, G.957 / TIA/EIA-526-4A / EIA/TIA-559	Fibre optic communication subsystem test procedures – Part 2-2- Digital systems – Optical eye pattern, waveform, and extinction ratio measurement
	1 GbE	IEEE	IEEE std 802.3-2002	2002	ANSI X3.230-1994[B20] (FC-PH)	IEEE Standard for Information technology--Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific requirements--Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications / Section 3 / Paragraph 38.6

Measurements	Technology	Standard Committees	Document Name	Date	Cross Reference	Title
	10 GbE		IEEE std 802.3ae-2002	2002		IEEE Standard for Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications-Media Access Control (MAC) Parameters, Physical Layer and Management Parameters for 10 Gb/s Operation / Annex
Optical modulation amplitude	10 GbE	IEEE	IEEE std 802.3ae-2002	2003		IEEE Standard for Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications-Media Access Control (MAC) Parameters, Physical Layer and Management Parameters for 10 Gb/s Operation / Paragraph 52.9
	FC	T11.2 / ANSI	T11.2 / ANSI FC-PI-2	2004	ANSI/TIA/EIA-526-4A-1997 (OFSTP-4A)	Fibre Channel- Physical Interfaces - 2
Optical power	1 GbE	IEEE	IEEE std 802.3-2002	2003	TIA/EIA-455-95	IEEE Standard for Information technology--Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific requirements--Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications / Section 3 / Paragraph 38.6
	10 GbE	IEEE	IEEE std 802.3ae-2002	2002	TIA/EIA-455-95	IEEE Standard for Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications-Media Access Control (MAC) Parameters, Physical Layer and Management Parameters for 10 Gb/s Operation / Paragraph 52.9
Q factor / BER	Any	IEC TC86C	86C/628/CDV IEC 61280-2-11 Ed 1.0	2004	IEC 61280-2-2 / ITU-T G.959.1	Fibre optic communication subsystem basic test procedure - Average Q- factor method using amplitude histogram evaluation for optical signal quality monitoring
			86C/396/CDV IEC 61280-2-8	2002	TIA/EIA-526-4A (OFSTP-4) / TIA/EIA-526-8 (OFSTP-8) / TIA/EIA-526-9 (OFSTP-9)	Q-factor test equipment to estimate the transmission performance of optical channels
		TIA/EIA	TIA/EIA-526-9: OFSTP9			Accelerated Measurement Procedure for Determininf BER and Q-Factor in Optical Transmission Systems Using the Variable Threshold Method

Measurements	Technology	Standard Committees	Document Name	Date	Cross Reference	Title
		ITU-T	ITU-T O.201	2003	ITU-T (G.691, G.707/Y.1322, G.709/Y.1331, G.825, G.8251, G.957, G.972, G.976, O.3, O.181), IEC 61300-3-29	Q-factor test equipment to estimate the transmission performance of optical channels
		TIA/EIA	TIA/EIA-526-8: OFSTP8			Accelerated Measurement of low BER in Digital Fibre Optic System
Relative intensity noise	FC	T11.2 / ANSI	T11.2 / ANSI FC-PI-2	2004		Fibre Channel- Physical Interfaces - 2
	1 GbE	IEEE	IEEE std 802.3-2002	2002	ANSI X3.230-199(FC-PH)	IEEE Standard for Information technology--Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific requirements--Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications / Section 3 / Paragraph 38.6
	10 GbE	IEEE	IEEE std 802.3ae-2002	2003	ANSI X3.230-199(FC-PH)	IEEE Standard for Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications-Media Access Control (MAC) Parameters, Physical Layer and Management Parameters for 10 Gb/s Operation / Paragraph 52.9
Relative Intensity noise optical modulation amplitude	10 GbE	IEEE	IEEE std 802.3ae-2002	2003		IEEE Standard for Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications-Media Access Control (MAC) Parameters, Physical Layer and Management Parameters for 10 Gb/s Operation / Paragraph 52.9
Rise time, fall time, overshoot	FC	T11.2 / ANSI	T11.2 / ANSI FC-PI-2	2004	ANSI/TIA/EIA-526-4A (OFSTP-4A)	Fibre Channel- Physical Interfaces - 2
	1 GbE	IEEE	IEEE std 802.3-2002	2002		IEEE Standard for Information technology--Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific requirements--Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications / Section 3 / Paragraph 38.6

Measurements	Technology	Standard Committees	Document Name	Date	Cross Reference	Title
	Any	IEC TC86C	86C/577/CDV IEC 61280-2-2 Ed 2.0	2003	IEC (60825-1, 61281-1, 61282-1) / ITU-T G.691, G.957 / TIA/EIA-526-4A / EIA/TIA-559	FIBRE OPTIC COMMUNICATION SUBSYSTEM TEST PROCEDURES – Part 2-2- Digital systems – Optical eye pattern, waveform, and extinction ratio measurement
	FC	T11.2 / ANSI	T11.2 / ANSI FC-MJSQ	2004	IEEE Std. 181, 1977 ‡ / IEEE Std. 194, 1977‡	Fibre Channel- Methodologies for Jitter and Signal Quality Specification
Skew	FC	T11.2 / ANSI	T11.2 / ANSI FC-PI-2	2004		Fibre Channel- Physical Interfaces - 2
Transmitter & receiver tests (sensitivity, upper cut off frequency) / eye mask	FC	T11.2 / ANSI	T11.2 / ANSI FC-PI-2	2004	FC-MJSQ, ANSI/TIA/EIA-526-4A (OFSTP-4A)	Fibre Channel- Physical Interfaces - 2
	1GbE	IEEE	IEEE std 802.3-2002	2002	ITU-T G.957	IEEE Standard for Information technology--Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific requirements--Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications / Section 3 / Paragraph 38.6
	10GbE		IEEE std 802.3ae-2002	2003	ANSI/TIA/EIA-526-4A-1997 (OFSTP-4A), ITU-T G.691	IEEE Standard for Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications-Media Access Control (MAC) Parameters, Physical Layer and Management Parameters for 10 Gb/s Operation / Paragraph 52.9
Wavelength and spectral width	1GbE	IEEE	IEEE std 802.3ae-2002	2002	TIA/EIA-455-127	IEEE Standard for Information technology--Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific requirements--Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications / Section 3 / Paragraph 38.6

‡ These two standards have been superseded by IEEE Std 181™-2003, 'IEEE Standard on Transitions,Pulses,and Related Waveforms'

Measurements	Technology	Standard Committees	Document Name	Date	Cross Reference	Title
	10GbE		IEEE std 802.3-2002	2003		IEEE Standard for Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications-Media Access Control (MAC) Parameters, Physical Layer and Management Parameters for 10 Gb/s Operation / Paragraph 52.9

13.13. Key parameters

This annex shows summary diagrams (Figure 9 to Figure 12) that indicate the relationships between the existing standards documents for the key parameters.

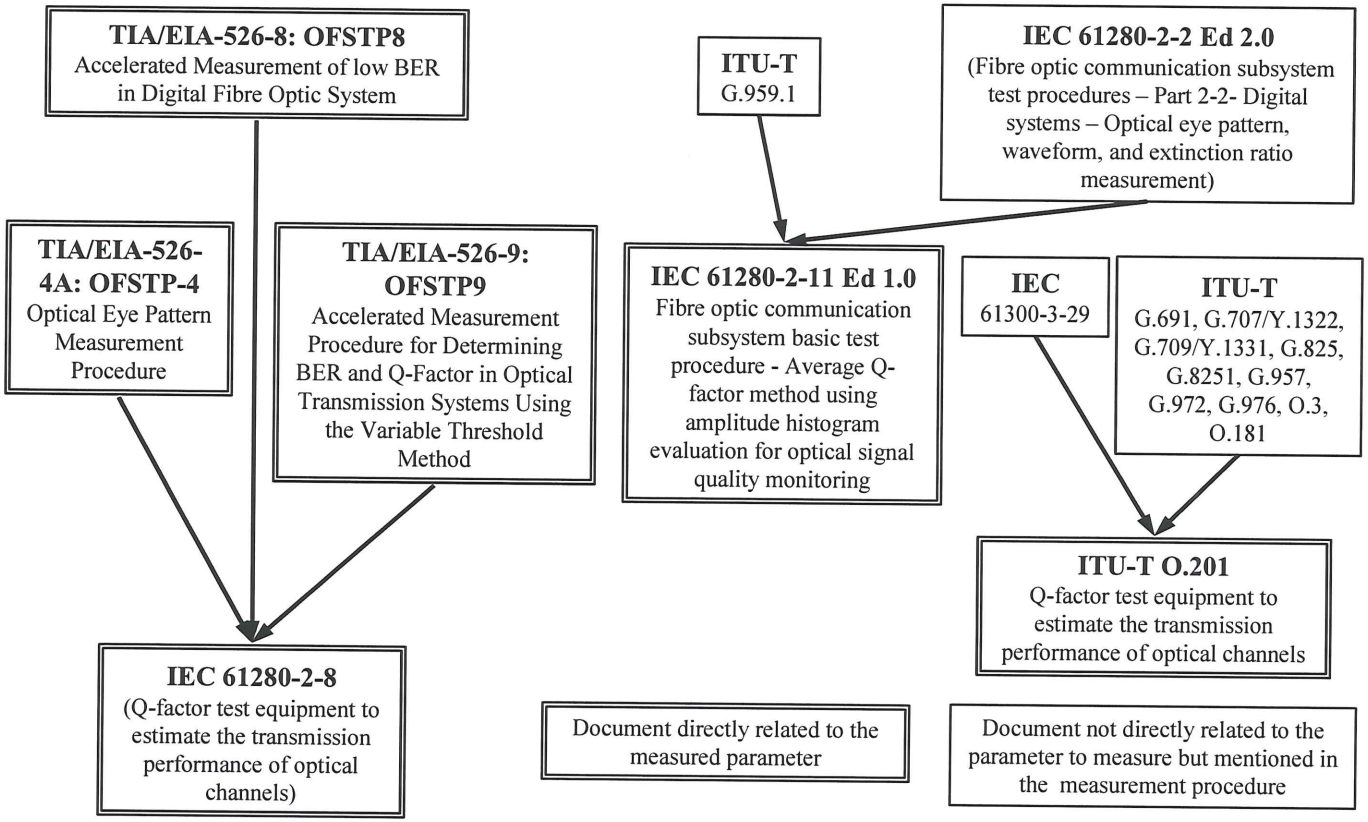


Figure 9 Relationship between standards for BER and Q factor

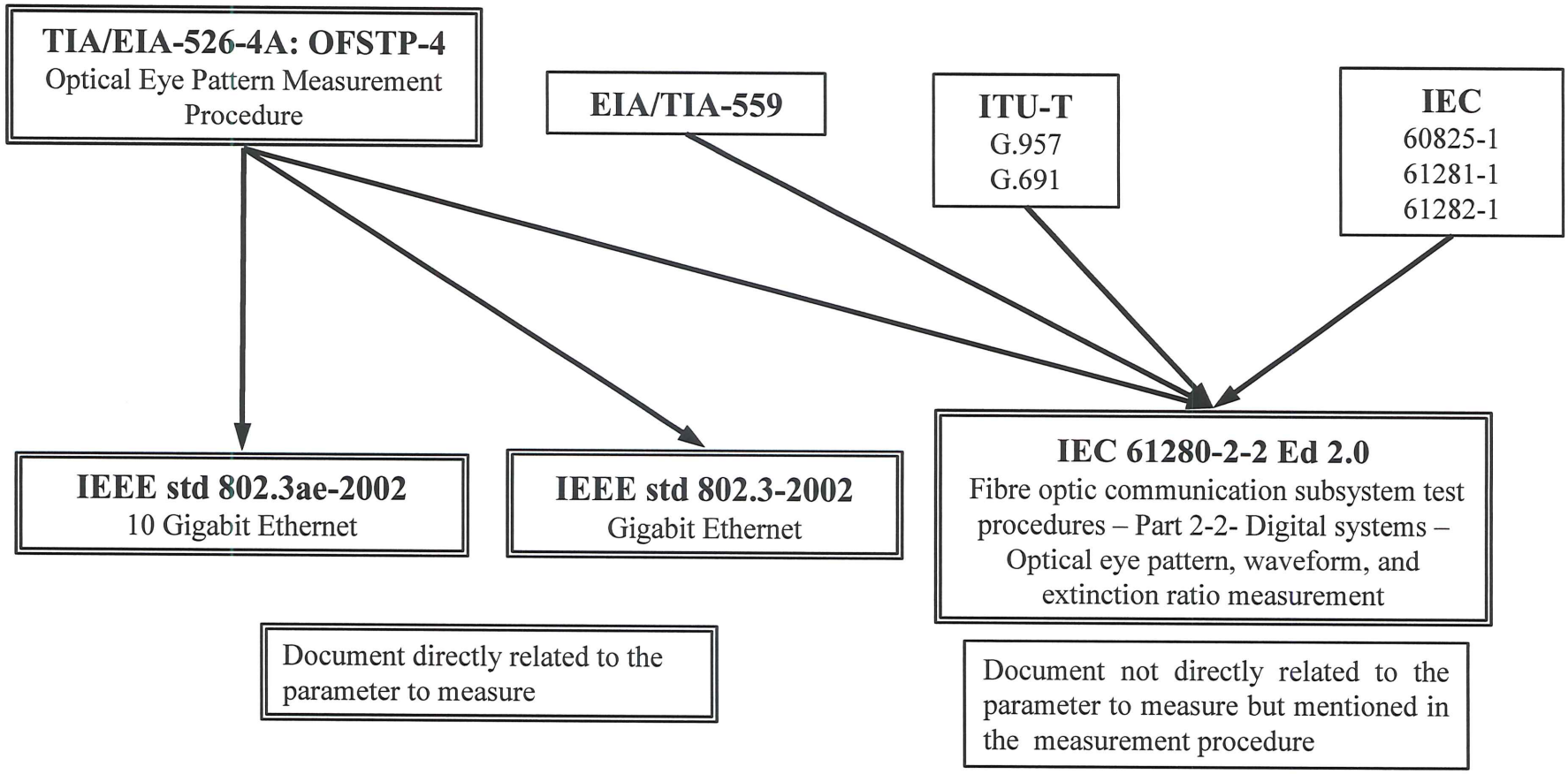


Figure 10 Relationship between standards for extinction ratio

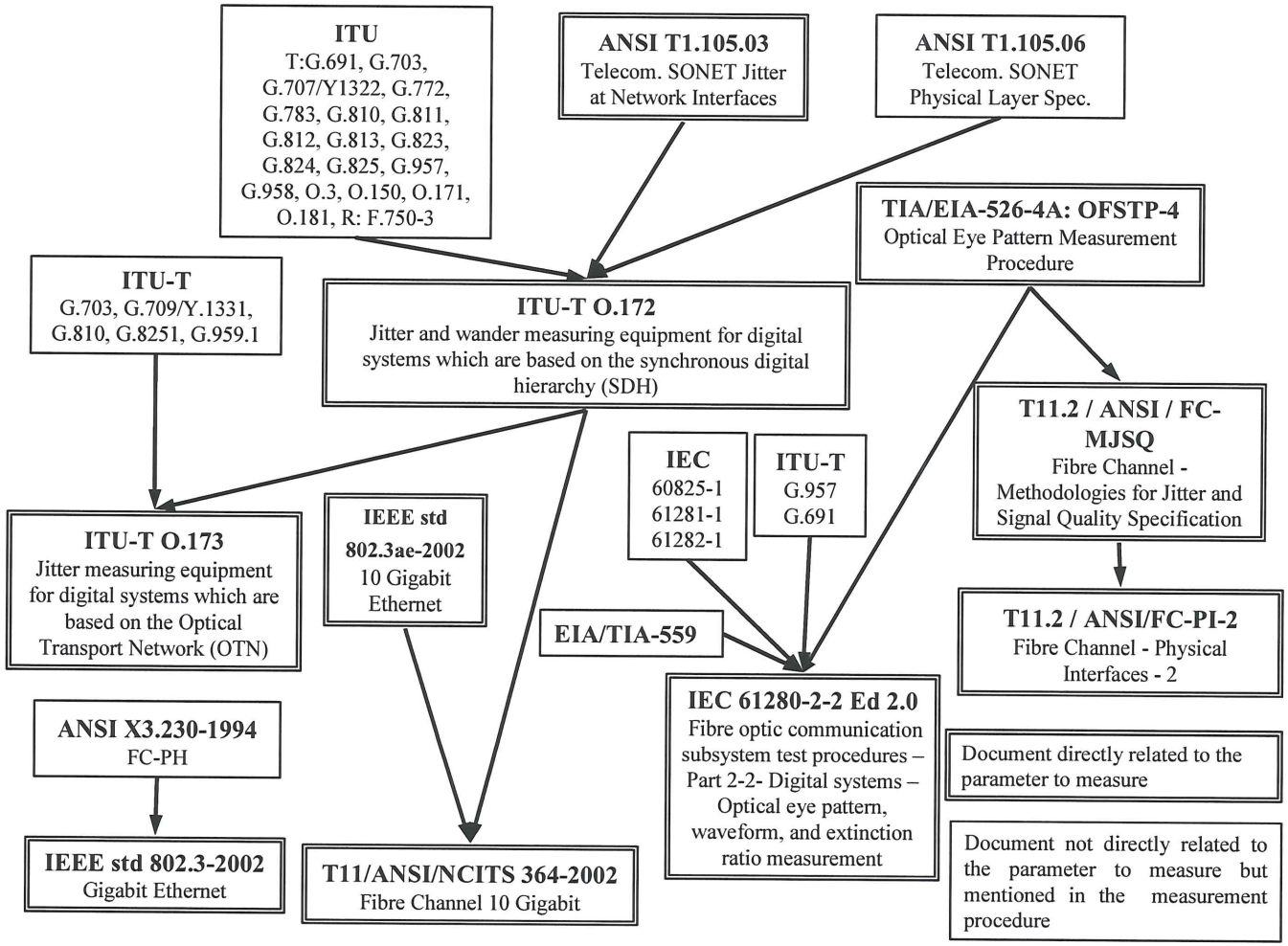


Figure 11 Relationship between standards for jitter

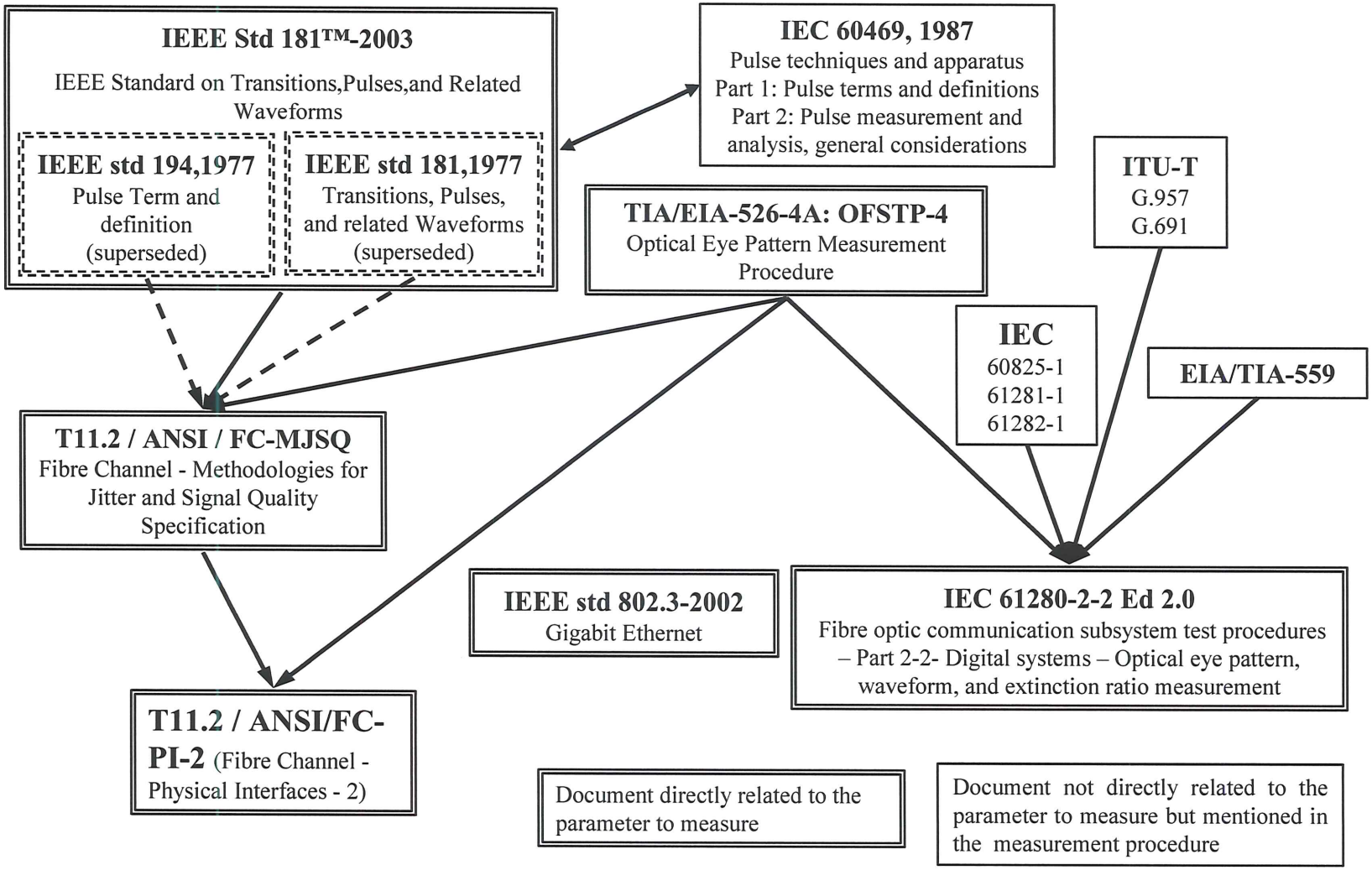


Figure 12 Relationship between standards for risetime, fall time and overshoot

14. Open Systems Interconnection (OSI) model

14.1. Overview

The International Standards Organisation (ISO) defined a ***7-layer model,*** shown in Figure 13, for network communication protocol. The model is more formally called the Open Systems Interconnection (OSI) model and can be applied to any network. The advantage of breaking down the protocol into layers is twofold:

- Each layer can be regarded as a black box.
  - Well defined inputs and outputs exist, but the Inner workings of the layer can be regarded as being independent
  - New versions, updates or better methods can be written without affecting the whole system.
  - Overall, the network is future-proofed to a great extent.
  - Benefits passed on to whole network.
- Communication need only take place at the layer appropriate for the task.

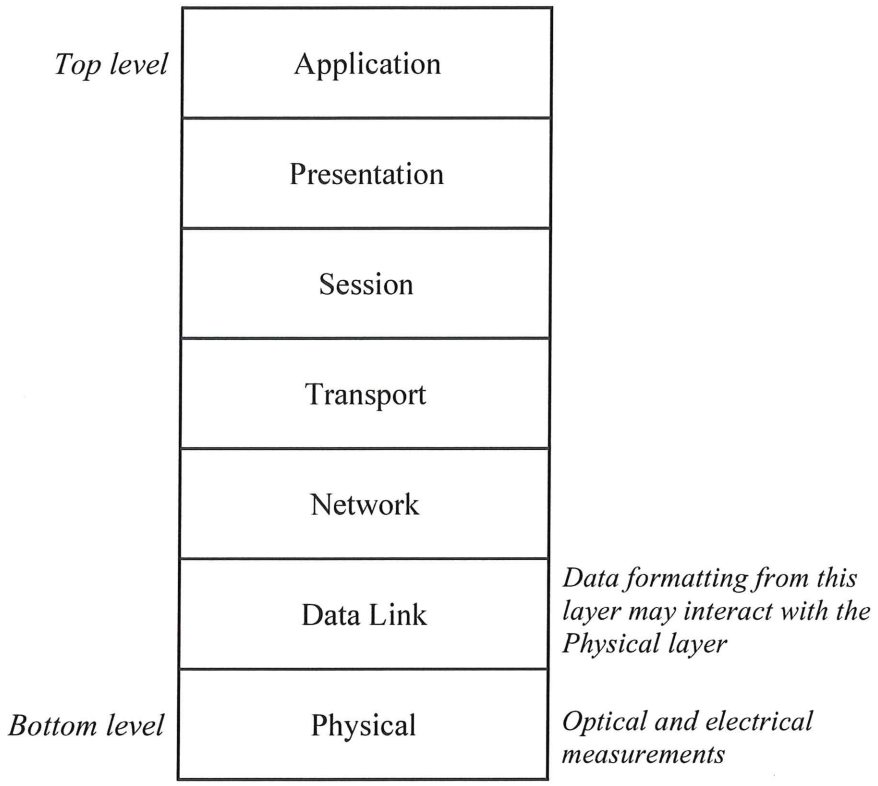


Figure 13 Open Systems Interconnection 7-layer model

14.2. Description of layer functions

14.2.1. Physical

This layer contains the physical implementation of the network or link. The layer transmits bits (ones and zeros) and defines how this data is transmitted over the network. This is the layer where measurement and measurement traceability is important. NPL can make contributions and impact at this point in the system. In the current application, we are considering optical transport.

14.2.2. Data Link

The data link provides low-level error detection and correction. For example if a packet is corrupted this layer is responsible for retransmitting the packet. This layer may interact with the Physical Layer, causing errors. Accurate measurement of these interactions will improve the performance of the system.

14.2.3. Network

This layer is responsible for routing packets of data across the network. For example, a large email file will be divided up into ***packets***, each packet addressed and sent out at this layer.

14.2.4. Transport

This is an intermediate layer that higher layers use to communicate to the network layer. This layer hides the complexities of low-level networking communication from the higher levels.

14.2.5. Session

This is the user's (transparent) interface into the network. The layer manages the 'current' connection (or session) to the network. Note: In packet-switched network a full-time network connection does exist, even though it may seem so. The Session layer keeps the communication flowing.

14.2.6. Presentation

The purpose of this layer is to ensure that the computers speak the same language. They convert text to ASCII or EBCDIC form and also encode or decode binary data for transport.

14.2.7. Application

The programs you use directly may need to communicate. For example, an email program or a file transfer would be applications.